

Some aspects of the orientation of galaxies in clusters *

Paulina Pajowska¹ Włodzimierz Godłowski²
Elena Panko³ Piotr Flin⁴

January 25, 2013

1. Uniwersytet Opolski, Institute of Physics, ul. Oleska 48, 45-052 Opole, Poland
e-mail: paoletta@interia.pl
2. Uniwersytet Opolski, Institute of Physics, ul. Oleska 48, 45-052 Opole, Poland
e-mail: godlowski@uni.opole.pl
3. Kalinenkov Astronomical Observatory, Nikolaev State University, Nikolaev, Ukraine
email: panko.elena@gmail.com
4. Pedagogical University, Institute of Physics, 25-406 Kielce, ul. Swietokrzyska 15, Poland
e-mail: sfflin@cyf-kr.edu.pl

Abstract

The analysis of Tully's groups of galaxies belonging to the Local Supercluster (LSC) was performed. In the 1975 Hawley and Peebles [1] presented the method for investigations of the galaxies orientation in the large structures. In our previous papers [2, 3] statistical test proposed by Hawley and Peebles for investigation of this problem was analyzed in details and some improvements were suggested. On this base the new method of the analysis of galactic alignment in clusters was proposed. Using this method, Godłowski [4] analyzed the orientation of galaxies inside Tully's group founding no significant deviations from isotropy both in orientation of position angles and δ_D and η angles as well, giving the spatial orientation of galaxy planes. In the present paper we examined carefully and methodically the dependence of alignment in Tully's groups on morphological type of galaxies. Moreover, we discussed the consequences of different approximation of "true shape" of the galaxies for different morphological types, possible influence of this problem for investigation of spatial orientation of galaxies. In addition, we discussed the implications of the obtained results for the theory of galaxy formation as well.

keywords angular momenta, galaxies, PACS 98.65.-r, 98.62.Ai

*Presented at The Sixth Scientific Conference "Selected Issues of Astronomy and Astrophysics" in honor of Bohdan Babiy 4-6 October 2011 Lviv.

1 Introduction

The aspect of structure formation in the Universe is one of the crucial problem of the modern extragalactic astronomy and cosmology. Moreover, since different scenarios of structure formation predicts different orientations of galaxies belonging to that structures [5, 6, 7, 8, 9, 10, 11, 12, 13], the investigation of the orientations of galaxies planes is regarded as a standard test of galaxies formation scenarios.

An interesting aspect of this problem consists in analysing the orientation of galaxies inside the galaxy structures. For the latest review of this problem see [14]. The very important question is whether exists the dependence on the alignment to the mass of the analyzed structure or not. Godłowski et al. [15] suggested that alignment of galaxies in cluster should increase with the number of a particular objects in the individual cluster. That hypothesis was confirmed qualitatively by Aryal et al. [16]. Godłowski et al. [2] verified this suggestion analysing sample of 247 rich Abell clusters using statistical tests and found out that alignment increases with the richness of the clusters.

Another aspect of this problem concerns with the orientation of galaxies in less massive, poor galaxy structures - groups of galaxies. It also should be noticed that for groups and clusters of galaxies there is no evidence of rotation. Moreover, Hwang and Lee [17] examined dispersions and velocity gradient of 899 Abell clusters and found a possible rotation in only six of them. Thus, any non-zero angular momentum of groups and clusters of galaxies would just come from possible alignment of galaxy spins.

The orientation of galaxies in clusters was investigated many times. Thompson [18] found alignment of galaxy orientations in the Virgo and A2197 clusters. Adams [19] discovered a bimodal distribution of galaxy orientations by examining the combined data for seven galaxy clusters (A76, A179, A194, A195, A999, A1016, A2197). The orientation of principal axes of the clusters corresponded with one of those maxima. Helou and Salpeter [20], studying 20 galaxies belonging to the Virgo cluster, found that their spins are not directed in random, however the nature of this nonrandom distribution was not too clear. MacGillivray and Dodd [21] investigated the distribution of orientation of galaxies in the Virgo cluster and showed that the galaxy planes are perpendicular to the direction towards the clusters center, i.e. the galaxies rotational axes are aligned towards that center.

On the other hand, Bukhari [22] as well as Bukhari and Cram [23] studying orientation of galaxies within clusters, did not recognize any alignment. Han et al. [24] probed a region of the LSC with an enhanced density galaxies. They analyzed a sample of 60 galaxies with well-known spins founding no alignment. Flin and Olowin [25] Trevese et al. [26] and Kim [27] investigating isolated Abell clusters, detected just rudimentary traces of alignment. The similar results were obtained by Torlina et al. [28] from studies of the Coma cluster and its vicinity. Gonzalez and Teodoro [29] interpreted the alignment of just the brightest galaxies within a cluster as an effect of action of gravitational tidal forces.

Summing up the results obtained by various authors, it can be stated that we have no satisfactory evidence to support the galaxy axis alignment in the groups and poor clusters of galaxies, while there is ample evidence of this kind for the rich clusters of galaxies. Additionally, it is obvious that in the isolated Abell groups the

brightest galaxies manifest a rudimentary alignment,[25, 26, 27] while in the most numerous clusters a non-random galaxy orientation alignment was found [16, 30, 31, 32, 33, 34].

The alignment of galaxies in the Tully’s groups of galaxies [35] was analyzed for the first time by Godłowski and Ostrowski [36]. For each cluster they studied the Δ_{11} parameter describing the galactic axes alignment with respect to a chosen cluster pole, divided by its formal error $\sigma(\Delta_{11})$ ($s \equiv \Delta_{11}/\sigma(\Delta_{11})$). The cluster pole coordinates change along the entire celestial sphere. The resulting maps were analyzed for correlations of their maxima with the important points on the maps. It was found that maxima correlate well with the direction of the line of sight. Godłowski and Ostrowski [36] concluded that this strong and systematic effect, was generated by the process of galactic axis de-projection from its optical image, is present in the catalogue data.

Tully’s groups were investigated again by Godłowski et al. [15]. In that paper it was found that the groups do not exhibit a clear evidence for existence of the alignment in the investigated structure. However, they concluded that the observational effect generated by the process of de-projection of galaxies [36] and later confirmed by [30, 31], mask any possible alignment with a high degree. For that reason the more detailed studies of the orientation of galaxy in Tully’s groups of galaxies were required. In the paper by Godłowski [4] it was shown that using ”true shape” i.e. true axis ratio of galaxies q_0 depending on morphological type according to Heidmann et al.[37] [hereafter HHV] with help of Fouque & Paturel [38] [hereafter FP] corrections of q to standard photometrical axial ratios, allowed us to avoid this problem. This gives much more powerful investigations of the spatial orientation of galaxies.

Moreover, using new method of the analysis of the galactic alignment in clusters proposed by [3] on the base of statistical test proposed by Hawley and Peebles [1], Godłowski [4] analyzed the orientation of galaxies inside Tully’s groups founding no significant deviation from isotropy both in orientation of position angles and δ_D and η angles giving the spatial orientation of galaxy planes. In the present paper we analyzed the dependence of the alignment in Tully’s groups on morphological type of galaxies.

2 Observational data

We analyzed the alignment of galaxies in galaxy groups belonging to the LSC. Groups were taken from Tully Nearby Galaxies (NBG) listed in the Catalogue [35]. This Catalogue contains 2367 galaxies with radial velocities less than 3000 km s^{-1} which give the possibility of remove the background objects. Tully’s Catalogue provides relatively uniform coverage of the entire unobscured sky [39]. Catalog do not contain the information about position angles of galaxies. It is the reason that position angles were taken from [40, 41, 42, 43] while some missing measurements were made on Palomar Sky Survey prints by Flin [44]. The NBG Catalogue gives the group affiliation for the galaxies belonging to the catalogue. In our opinion, the groups extracted from the NBG Catalogue are one of the best selections with precise criterion of groups membership. The galaxy distances are based on velocities,

assuming the flat cosmological model ($q_0 = 1/2$) with $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and the model describing velocity perturbations in the vicinity of the Virgo Cluster [45] It means, that the galaxy distances are very well and in uniform maner determined. As a result the lists of galaxies belonging to the particular groups are free from the foreground and background objects which is crucial in such type of the analysis. For our study we use only those groups from NBC Catalogue which have at least 40 members.

3 Methods of the investigations

One should note that two main methods for the study of the galaxy orientation were proposed till now. In the first one [1] the distribution of the position angle of the galactic image major axis was analyzed. The second approach is based on the de-projection of the galaxy images, where the galaxy's inclination with respect to the observer's line of sight i is considered. The latter method allowed us to use also the face-on galaxies, in contrast to investigations of the position angles where face-on and nearly face-on galaxies should be excluded from the consideration. This method was originally proposed by Öpik [46], applied by Jaaniste & Sarr [47] and significantly modified by Flin & Godłowski [48, 49, 50, 51, 52, 44] (see also [53]).

In the Tully's NBG Catalogue [35] the inclination angle was calculated according to the formula: $i = \cos^{-1}(q^2 - q_0^2)/(1 - q_0^2)^{-1/2} + 3^0$, where $q = d/D$ is the ratio of the minor to the major axis diameters and q_0 is "true" axial ratio. Tully used a standard value $q_0 = 0.2$. Worthy of note is that above formula is the modified Holmberg's [54] formula for oblate spheroids. For each galaxy, two angles are determined: δ_D - the angle between the normal to the galaxy plane and the main plane of the coordinate system, and η - the angle between the projection of this normal onto the main plane and the direction towards to the zero initial meridian. Using the Supergalactic coordinate system (Flin & Godłowski [48] based on [55]) the following relations between angles (L , B , P) and (δ_D , η) are hold:

$$\sin \delta_D = -\cos i \sin B \pm \sin i \cos r \cos B, \quad (1)$$

$$\sin \eta = (\cos \delta_D)^{-1} [-\cos i \cos B \sin L + \sin i (\mp \cos r \sin B \sin L \pm \sin r \cos L)], \quad (2)$$

$$\cos \eta = (\cos \delta_D)^{-1} [-\cos i \cos B \cos L + \sin i (\mp \cos r \sin B \cos L \mp \sin r \sin L)], \quad (3)$$

where $r = P - \pi/2$.

In order to detect non-random effects in the distribution of the investigated angles: δ_D , η and P we divided the entire range of the analyzed angles into 18 bins and carried out three different statistical tests. These tests were : the χ^2 test, the autocorrelation test and the Fourier test [1, 51, 52, 2, 3].

Let N denotes the total number of galaxies in the considered cluster, and N_k - the number of galaxies with orientations within the k -th angular bin. Moreover, $N_{0,k}$ denotes the expected number of galaxies in the k -th bin. In our case all $N_{0,k}$ are equal N_0 , which is also mean number of galaxies per bin.

Our first test is the χ^2 test:

$$\chi^2 = \sum_{k=1}^n \frac{(N_k - N p_k)^2}{N p_k} = \sum_{k=1}^n \frac{(N_k - N_{0,k})^2}{N_{0,k}}, \quad (4)$$

where p_k is a probability that chosen galaxy falls into k th bin. We divided entire range of a θ angle into n bins, which gives $(n-1)$ degrees of freedom in the χ^2 test. It means that the expected value $E(\chi^2) = n-1$ while variance $\sigma^2(\chi^2) = 2(n-1)$. For $n = 18$ the χ^2 test yields a critical value 27.59 (at the significance level $\alpha = 0.05$).

The second auto-correlation test quantifies the correlations between galaxy numbers in neighboring angle bins. The measure of the correlation is defined as:

$$C = \sum_{k=1}^n \frac{(N_k - N_{0,k})(N_{k+1} - N_{0,k+1})}{[N_{0,k}N_{0,k+1}]^{1/2}}, \quad (5)$$

where $N_{n+1} = N_1$. Hawley and Peebles [1] noted that in the case of an isotropic distribution, we expect $C = 0$ with the standard deviation $\sigma(C) = n^{1/2}$. Godłowski [3], analysing case that all $N_{0,k}$ were equal, showed that in these case the expected value $E(C) = -1$, while critical value for autocorrelation test was $C_{cr} \approx 6.89$. The latter value was obtained from numerical simulations using the method described by Godłowski [3].

If deviation from isotropy is a slowly varying function of the angle θ one can use the Fourier test [1, 51, 52]:

$$N_k = N_{0,k}(1 + \Delta_{11} \cos 2\theta_k + \Delta_{21} \sin 2\theta_k), \quad (6)$$

we obtain the following expressions for the Δ_{i1} coefficients:

$$\Delta_{11} = \frac{\sum_{k=1}^n (N_k - N_{0,k}) \cos 2\theta_k}{\sum_{k=1}^n N_{0,k} \cos^2 2\theta_k}, \quad (7)$$

$$\Delta_{21} = \frac{\sum_{k=1}^n (N_k - N_{0,k}) \sin 2\theta_k}{\sum_{k=1}^n N_{0,k} \sin^2 2\theta_k}. \quad (8)$$

Standard deviation of $\sigma(\Delta_{11})$ and $\sigma(\Delta_{12})$ is given by expressions:

$$\sigma(\Delta_{11}) = \left(\sum_{k=1}^n N_{0,k} \cos^2 2\theta_k \right)^{-1/2} \approx \left(\frac{2}{nN_0} \right)^{1/2}, \quad (9)$$

$$\sigma(\Delta_{21}) = \left(\sum_{k=1}^n N_{0,k} \sin^2 2\theta_k \right)^{-1/2} \approx \left(\frac{2}{nN_0} \right)^{1/2}. \quad (10)$$

The probability that the amplitude

$$\Delta_1 = (\Delta_{11}^2 + \Delta_{21}^2)^{1/2} \quad (11)$$

is greater than a certain chosen value is given by the formula:

$$P(> \Delta_1) = \exp \left(-\frac{n}{4} N_0 \Delta_1^2 \right). \quad (12)$$

This test was substantially improved by Godłowski for the case when higher Fourier mode is taken into account:

$$N_k = N_{0,k}(1 + \Delta_{11} \cos 2\theta_k + \Delta_{21} \sin 2\theta_k + \Delta_{12} \cos 4\theta_k + \Delta_{22} \sin 4\theta_k + \dots). \quad (13)$$

In this case the amplitude Δ instead Δ_1 is considered. When we investigate simple case of position angles distribution, Δ^2 is given by simple formula: $\Delta^2 = \Delta_{11}^2 + \Delta_{21}^2 + \Delta_{12}^2 + \Delta_{22}^2$ (see [52, 3] for details).

The isotropy of the resultant distributions of the investigated angles was also analyzed by Kolmogorov-Smirnov test (K-S test). We assumed that the theoretical, random distribution contains the same number of objects as the observed one. In order to reject the H_0 hypothesis, that the distribution is random one, the value of observed statistics λ should be greater than $\lambda_{cr} = 1.358$ (for $\alpha = 0.05$). However one should note, that especially in the case of position angles, the number of analyzed galaxies is sometimes small and does not satisfy theoretical tests conditions. That is the reason we repeated our analysis with different numbers of bins, and revealed insignificant differences in these cases.

4 The results

The results were presented in the Tables 1-20. At first, we analyzed the orientation of galaxies in Tully's groups using, for obtaining δ_D and η angles, inclinations angles taken directly from NGB Catalogue [35] (sample A). These results were shown in the Tables 1-9.

For the sample of *All* galaxies the analysis of the supergalactic position angles has shown that only one group (61) exhibits the alignment of galaxies. Analysis of the distribution of the angles giving spatial orientation of galaxies (δ_D and η) seems to show a weak alignment. For δ_D angle the tests showed that distributions can be non random in the case of the clusters 11, 31, 51 41 and 52. For η angle we found a possible alignment in the case of clusters 11, 12, 41, 52, 64, 31 and 51. However, in the paper by Godłowski [4] it was shown that this alignment is disappeared when we avoid the assumption that the "true" axial ratio is $q_0 = 0.2$, which is a rather poor approximation, especially for non-spiral galaxies. Because of the NGB Catalogue contains morphological types of galaxies it allowed us to use different values of q_0 depending on morphological type [37]. With help by Fouque & Paturel [38] formulae, which convert q to the standard photometrical axial ratios, the new inclination angle i for all galaxies in NGB catalogue was computed. The results of our investigations for that "new" sample of galaxies (sample B) are presented in Tables 10-18. Please note that above procedure do not change the position angles of galaxies, instead of the case of position angle P , sample B is related to only those galaxies were the certainly measured angles were taking into account.

Returning to the analysis of samples *A* divided according to morphological type, we do not find any alignment for spiral (*SP*) galaxies while for sample of non-spiral (*NSP*) galaxies we found non randomness in the distributions of δ_D and η angles for fifth and seventh groups respectively. During analysis of the sample B we observed disappearing of the alignment. For position angles P we do not observe any alignment. During analysis the δ_D angle for spiral galaxies we observed an alignment for the group 53 while for non-spiral we observed alignment for groups 11 and 51. In the case of the η angle the non randomness was observed in two groups for *All* galaxies (groups 11 and 41) and in four groups (11, 14, 42 and 52) for non-spiral galaxies. It confirms Godłowski' [4] conclusion that any possibly observed alignment

for the galaxies in sample *A* is caused by the reason of the wrong assumption the "true" axial ratio especially for non-spiral galaxies.

For more detailed analysis we used the method described in [3]. Our question is, whether we could say that we found an alignment in the whole analyzed sample of 18 Tully's groups of galaxies or not. So we computed the mean value and the variance of analyzed statistics: χ^2 , $\Delta_1/\sigma(\Delta_1)$, $\Delta/\sigma(\Delta)$ (i.e. the same statistics were analyzed in [2]) for our sample of 18 groups and compared them with the results of numerical simulations. We performed 1000 simulations of 18 fictitious clusters, each with a number of randomly oriented, galaxy's members, the same as in real clusters separately for *All* (see [4]), for spiral, and for non-spiral galaxies. In the Table 19 we presented average values of the analyzed statistics, their standard deviations, standard deviations in the sample as well as their standard deviations for distribution of *P* angles, obtained from numerical simulations. One should note, that there are some differences in the results of numerical simulations for *P*, δ_D and η angles but it does not change our further conclusions.

The mean values and variance of analyzed statistics for sample of real clusters were presented in the Table 20. It shows that (for sample A) analysis of the position angles for *All* and spiral galaxies does not show a significant deviation from the values expected in the case of random distributions, while marginal effect is observed for non-spiral galaxies. The analysis of δ_D and η angles shows the existence of alignment at the 2σ level (with exception of $\Delta/\sigma(\Delta)$ statistics for δ_D angle) for subsample of *All* galaxies and even stronger effect for non-spiral galaxies. The spiral galaxies do not show this effect. For the sample *B* generally we do not observe the deviation from the values expected in the case of random distributions. The above results allowed us to conclude that we did not observe any significant alignment for Tully's groups of galaxies.

5 Discussion and conclusions

In the present paper an investigation of the orientation of galaxies inside 18 Tully's groups of galaxies belonging to the Local Supercluster divided according to morphological type was performed. We do not find any significant alignment in the orientation of galaxies in the analyzed groups of galaxies. As a result we concluded that the orientations of galaxies in the Tully's groups are random. Presence of a possible weak alignment for spiral galaxies needs more investigations in the future. We also analyzed observational effect generated by the process of deprojection of galaxies found by Godłowski and Ostrowski [36], which masks to the high degree any possible alignment during analysis of the spatial orientation of galaxies in clusters. We confirmed Godłowski's suggestion [14, 4] that this effect is because of wrong approximation of the "true shape" of galaxies, especially for non-spiral galaxies. We've shown that using "true shape" of galaxies q_0 depending on morphological type according to Heidmann et al. [37] with help of Fouque & Paturel [38] corrections of q to standard photometrical axial ratios, allowed us to avoid this problem. This gives much more powerful investigation of the spatial orientation of galaxies.

Our results, lack of the alignment for less masive galaxies structures together with results of our previous papers [30, 31, 44, 14, 3] confirms our suggestion that

alignment of galaxies increases with the mass of the structures [15, 14]. Similar result was also obtain by Aryal et al. [16] based on the series of theirs papers [56, 57, 58]. In our opinion the observed relation between the richness of galaxy cluster and the alignment is due to tidal torque, as suggested by [59], however it is also in agreement with prdiction of the Li model [60] in which galaxies form in the rotating universe.

It should be noticed that Gonzalez and Teodoro [29] interpreted the alignment of just the brightest galaxies within a cluster as an effect of action of gravitational tidal forces. Recently, there have been also some attempts to investigate galaxy angular momenta on a large scale. Paz, Stasyszyn and Padilla [61] analysing galaxies from the Sloan Digital Sky Survey catalogue found that the galaxy angular momenta are aligned perpendicularly to the planes of large-scale structures, while there is no such effect for the low-mass structures. They interpret this as consistent with their simulations based on the mechanism of tidal interactions. Jones, van der Waygaert and Aragon-Calvo [62] found that the spins of spiral galaxies located within cosmic web filaments tend to be aligned along the larger axis of the filament, which they interpreted as "fossil" evidence indicating that the action of large scale tidal torques effected the alignments of galaxies located in cosmic filaments.

In the commonly accepted Λ CDM model, the Universe deems to be spatially flat, as well as homogeneous and isotropic at appropriate scale. In this model the structure were formed from the primordial adiabatic, nearly scale invariant Gaussian random fluctuations [63, 64, 65]. This picture is in agreement with both the numerous numerical simulations [66, 67, 68, 69] and the observations.

Usually, dependence between the angular momentum and the mass of the structure is presented as the empirical relation $J \sim M^{5/3}$ [70, 71, 72, 73, 61, 74], for rewiev see also [75]. In our opinion, it is due to tidal torque, as suggested by [76, 59]. Also [77, 78] analysing of the linear tidal torque theory noticed the connection of the alignment with the considered scale of structure. However, another possibilities, as Li model [60] for example, are also not excluded.

References

- [1] Hawley, D. I., Peebles, P. J. E. 1975, *Astron.J.*, 80, 477
- [2] Godłowski, W., Piwowska, P., Panko, E., Flin, P., 2010, *Astron.J.*, 723, 985
- [3] Godłowski, W., 2012, *Astrophys. J.*, 747, 7
- [4] Godłowski, W., 2011, *Acta Physica Polonica B*, 42, 2323
- [5] Peebles, P.J.E. 1969, *Astron.J.*, 155, 393
- [6] Zeldovich, B. Ya. 1970, *A&A*, 5, 84
- [7] Sunyaev, A. R., Zeldovich, Ya. B., 1972 *A&A*, 20, 189
- [8] Doroshkevich, A. G. 1973, *Astrophys. Lett.*, 14, 11
- [9] Shandarin, S.F. 1974, *Sov. Astr.*, 18, 392

Table 1: Test for isotropy of the orientations of galaxy plane. The distribution of the angle δ of galaxies, inclination was taken directly from NGC Catalogue.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
δ	11	62.8	9.50	.000	.000	1.20	-4.09
	12	25.7	-11.48	.299	.634	0.55	-1.56
	13	29.7	-6.94	.915	.944	0.62	0.02
	14	24.0	3.52	.170	.254	0.78	-1.69
	15	13.1	-1.88	.791	.729	0.59	-0.03
	17	13.8	-5.50	.621	.743	0.82	-0.61
	21	14.2	0.24	.120	.299	1.14	-0.38
	22	7.0	0.68	.546	.857	0.62	0.75
	23	17.0	-1.82	.613	.701	0.47	0.96
	31	33.7	15.98	.000	.002	1.79	1.36
	41	22.8	6.54	.049	.012	1.37	-0.04
	42	24.7	-3.78	.401	.444	0.75	0.58
	44	26.7	7.95	.047	.050	1.34	-1.22
	51	29.6	-0.41	.025	.018	1.44	0.96
	52	21.6	3.04	.011	.040	1.42	-1.81
	53	13.3	-3.29	.556	.821	0.62	-0.60
	61	19.9	-3.13	.834	.175	0.62	-0.54
	64	28.7	-7.54	.180	.488	0.84	0.55

Table 2: Test for isotropy of the orientations of galaxy plane. The distribution of the angle δ of galaxies, SP galaxies, inclination was taken directly from NGC Catalogue.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
δ	11	27.6	-1.85	.278	.517	0.68	-1.59
	12	21.3	-9.50	.582	.844	0.41	-1.01
	13	30.4	-9.00	.314	.281	0.69	1.34
	14	15.4	-1.25	.907	.635	0.43	0.37
	15	12.9	-1.51	.595	.729	0.72	0.79
	17	13.6	-8.66	.947	.975	0.46	-0.13
	21	12.3	-0.52	.636	.403	0.64	0.17
	22	17.7	-0.69	.063	.197	1.12	1.63
	23	15.7	-1.34	.377	.393	0.77	1.18
	31	22.9	4.52	.024	.105	1.27	1.07
	41	22.9	4.91	.487	.033	0.80	0.18
	42	20.2	-4.17	.807	.303	0.60	0.58
	44	12.9	0.83	.371	.453	0.63	-1.04
	51	16.6	-4.99	.729	.582	0.55	0.53
	52	19.0	-1.47	.057	.213	1.07	-1.59
	53	19.7	-1.92	.120	.196	1.05	-1.20
	61	19.0	-5.70	.565	.392	0.65	0.37
	64	20.7	-2.31	.789	.668	0.37	0.29

Table 3: Test for isotropy of the orientations of galaxy plane. The distribution of the angle δ of galaxies, NSP galaxies, inclination was taken directly from NGC Catalogue.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
δ	11	93.3	4.00	.000	.000	1.80	-5.10
	12	26.6	-5.46	.362	.481	0.75	-1.35
	13	34.6	-1.84	.274	.125	0.69	-1.60
	14	26.3	8.14	.011	.689	1.07	-2.67
	15	21.5	4.03	.027	.060	1.48	-1.34
	17	11.9	0.45	.526	.688	0.72	-0.79
	21	32.9	-3.95	.038	.077	1.58	-1.01
	22	15.3	-1.46	.440	.396	0.96	-0.91
	23	13.3	-1.20	.735	.724	0.73	-0.10
	31	27.0	5.30	.007	.468	1.45	0.87
	41	18.1	1.02	.038	.491	1.39	-0.31
	42	21.8	2.01	.195	.472	1.07	0.17
	44	22.5	7.63	.052	.126	1.40	-0.64
	51	33.3	7.58	.001	.033	2.05	0.94
	52	22.9	2.63	.160	.058	1.23	-0.90
	53	32.1	14.22	.000	.136	2.01	0.73
	61	23.6	0.99	.094	.035	1.03	-1.77
	64	23.2	-0.18	.090	.453	1.17	0.53

Table 4: Test for isotropy of the orientations of galaxy plane. The distribution of the angle η of galaxies, inclination was taken directly from NGC Catalogue.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
η	11	60.0	5.96	.000	.000	2.00	-4.09
	12	28.5	7.56	.001	.010	1.70	-1.56
	13	25.6	2.78	.079	.105	0.77	0.02
	14	27.4	6.63	.090	.148	1.00	-1.69
	15	22.9	2.51	.764	.209	0.91	-0.03
	17	13.1	-5.97	.470	.820	0.46	-0.61
	21	26.9	-3.55	.054	.202	1.23	-0.38
	22	11.7	5.57	.177	.224	0.98	0.75
	23	20.2	-0.10	.081	.232	1.09	0.96
	31	24.0	0.43	.046	.036	1.56	1.36
	41	27.2	10.22	.001	.002	1.95	-0.04
	42	15.9	3.30	.033	.069	1.24	0.58
	44	20.4	-3.05	.226	.138	0.78	-1.22
	51	30.6	-5.37	.042	.125	1.15	0.96
	52	38.1	12.29	.001	.001	1.92	-1.81
	53	12.2	-8.28	.816	.949	0.34	-0.60
	61	23.7	-12.56	.549	.511	0.64	-0.54
	64	50.1	-3.53	.002	.000	1.88	0.55

Table 5: Test for isotropy of the orientations of galaxy plane. The distribution of the angle η of galaxies, SP galaxies, inclination was taken directly from NGC Catalogue.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
η	11	32.1	-3.44	.070	.043	1.17	2.30
	12	18.7	2.93	.099	.133	1.17	-0.17
	13	25.8	1.92	.519	.115	1.16	1.04
	14	12.9	0.37	.372	.356	0.71	-1.38
	15	25.5	2.89	.537	.168	0.97	0.63
	17	8.0	-2.57	.707	.948	0.67	0.48
	21	14.6	1.00	.216	.424	0.89	1.12
	22	16.3	3.92	.481	.142	0.87	1.10
	23	14.5	-2.73	.777	.884	0.44	-0.34
	31	22.7	1.27	.181	.079	1.38	1.19
	41	16.3	6.14	.023	.069	1.34	2.48
	42	13.4	-6.50	.712	.947	0.48	-0.09
	44	16.5	-5.62	.308	.427	0.59	1.17
	51	34.8	-6.10	.421	.603	0.98	0.69
	52	25.8	4.05	.043	.092	1.19	1.06
	53	16.6	-8.13	.423	.623	0.53	0.30
	61	24.5	-7.82	.343	.159	1.14	0.83
	64	20.2	-5.73	.339	.281	0.86	1.21

Table 6: Test for isotropy of the orientations of galaxy plane. The distribution of the angle η of galaxies, NSP galaxies, inclination was taken directly from NGC Catalogue.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
η	11	67.2	32.17	.000	.000	1.92	6.53
	12	26.6	12.58	.002	.003	1.40	-1.45
	13	22.1	-1.12	.097	.164	1.19	1.78
	14	52.4	16.75	.001	.001	1.53	2.45
	15	13.0	3.00	.879	.264	0.50	-0.46
	17	18.9	-0.12	.019	.091	1.24	-1.14
	21	32.6	-10.03	.066	.195	0.89	-0.58
	22	6.4	1.35	.309	.523	0.56	1.09
	23	22.5	3.08	.006	.036	1.39	-1.71
	31	13.8	0.27	.139	.407	0.91	1.91
	41	26.7	2.18	.019	.047	1.48	1.59
	42	30.5	13.91	.001	.000	1.89	0.87
	44	23.4	-3.57	.551	.390	0.94	-0.01
	51	25.2	6.91	.006	.013	0.96	3.21
	52	27.2	14.91	.009	.001	1.78	2.08
	53	8.3	-1.85	.695	.899	0.38	-0.31
	61	22.8	0.00	.012	.048	1.38	0.63
	64	47.0	5.50	.001	.000	2.00	3.19

Table 7: Test for isotropy of the orientations of galaxy plane. The distribution of the angle P of galaxies.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
P	11	22.7	-11.42	.728	.756	0.53	0.78
	12	17.6	-1.57	.198	.302	0.88	-0.61
	13	13.4	-2.48	.714	.621	0.41	-0.28
	14	14.9	-1.05	.990	.204	0.49	-0.09
	15	11.3	-0.75	.185	.382	1.06	-0.03
	17	10.7	-5.64	.727	.734	0.62	-0.50
	21	13.5	-2.84	.878	.936	0.67	-0.38
	22	16.0	-1.98	.910	.895	0.63	-0.41
	23	12.3	0.27	.230	.453	0.81	-1.37
	31	20.1	1.00	.729	.204	0.82	0.46
	41	20.0	10.67	.595	.005	1.09	-0.58
	42	19.0	1.51	.124	.222	0.91	-1.51
	44	18.9	1.64	.367	.726	0.98	0.57
	51	23.1	3.00	.576	.045	0.88	-1.04
	52	14.8	-0.32	.631	.798	0.77	0.77
	53	17.5	2.82	.080	.192	1.36	1.61
	61	27.9	6.48	.007	.002	1.68	-0.76
	64	18.4	2.10	.295	.419	0.91	-1.56

Table 8: Test for isotropy of the orientations of galaxy plane. The distribution of the angle P of galaxies, SP galaxies.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
P	11	21.8	-9.88	.821	.853	0.50	-0.18
	12	14.1	0.55	.173	.339	0.86	-0.54
	13	15.6	4.80	.430	.073	0.79	-1.21
	14	16.3	4.30	.326	.167	0.74	-0.65
	15	12.2	-2.00	.294	.566	0.96	-0.38
	17	11.7	-5.00	.702	.733	0.62	0.00
	21	22.2	-8.00	.577	.636	0.93	-1.03
	22	16.3	-1.67	.416	.717	0.77	-1.28
	23	12.8	1.69	.272	.270	0.78	-0.74
	31	14.1	-2.12	.532	.416	0.57	-0.26
	41	21.7	10.32	.972	.003	0.78	-0.07
	42	14.7	1.86	.146	.194	0.80	-1.02
	44	16.0	-3.00	.371	.700	0.71	0.46
	51	23.9	-0.67	.686	.041	0.84	-0.84
	52	12.2	-2.95	.533	.851	0.56	0.99
	53	16.4	-3.55	.508	.613	0.78	0.66
	61	21.0	1.51	.060	.036	1.25	-0.43
	64	16.0	0.70	.683	.344	1.07	-0.66

Table 9: Test for isotropy of the orientations of galaxy plane. The distribution of the angle P of galaxies, NSP galaxies.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
P	11	22.7	4.66	.044	.031	0.81	1.99
	12	18.3	-1.08	.926	.931	0.41	-0.27
	13	14.2	-2.90	.475	.432	0.57	1.04
	14	19.3	-4.94	.399	.270	0.57	0.54
	15	18.8	-2.80	.451	.326	1.02	0.68
	17	14.5	-3.50	.703	.769	0.63	-0.83
	21	16.9	-7.35	.604	.846	0.36	0.96
	22	20.0	-1.38	.600	.798	0.61	0.99
	23	26.4	-7.00	.269	.379	0.65	-1.54
	31	27.2	3.62	.250	.148	1.34	1.51
	41	11.0	-0.25	.312	.526	0.86	-0.96
	42	19.8	-1.80	.396	.743	0.65	-1.34
	44	16.1	0.71	.898	.844	0.84	0.34
	51	14.3	1.43	.585	.847	0.62	-0.63
	52	30.0	6.00	.104	.045	1.73	-0.19
	53	17.3	4.18	.039	.164	1.37	2.08
	61	16.9	5.29	.051	.067	1.34	-0.90
	64	20.1	0.45	.168	.321	0.80	-1.74

Table 10: Test for isotropy of the orientations of galaxy plane. The distribution of the angle δ of galaxies, inclination was obtained according to HHV and FP corrections.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
δ	11	14.3	-2.46	.504	.848	0.39	-1.17
	12	12.4	2.49	.749	.680	0.37	0.74
	13	8.7	0.86	.403	.694	0.54	1.25
	14	22.7	1.50	.658	.466	0.52	-0.89
	15	26.2	4.40	.038	.034	1.25	1.90
	17	7.0	-1.57	.959	.917	0.48	-0.11
	21	19.7	6.05	.615	.049	0.85	0.72
	22	17.9	1.77	.062	.128	1.30	1.44
	23	22.1	-3.00	.155	.266	0.71	1.88
	31	19.1	3.90	.095	.245	0.74	0.50
	41	20.9	-4.77	.374	.476	0.69	1.26
	42	18.3	-4.08	.462	.293	0.86	-0.95
	44	23.9	0.74	.581	.115	0.93	-0.63
	51	18.3	3.40	.826	.851	0.61	0.32
	52	20.7	4.97	.013	.043	1.53	-1.51
	53	13.2	-1.46	.696	.720	0.62	-0.67
	61	25.3	-1.26	.452	.376	1.03	-0.22
	64	25.9	-1.99	.227	.354	0.78	0.06

Table 11: Test for isotropy of the orientations of galaxy plane. The distribution of the angle δ of galaxies, SP galaxies, inclination was obtained according to HHV and FP corrections.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
δ	11	19.7	-4.98	.894	.402	0.44	0.36
	12	19.0	-5.69	.979	.716	0.51	0.20
	13	29.4	1.55	.085	.066	0.85	2.01
	14	17.8	1.49	.796	.139	0.60	0.65
	15	18.6	-4.82	.330	.624	0.93	0.96
	17	10.0	-3.30	.910	.947	0.52	0.20
	21	19.6	-3.88	.794	.176	0.89	0.41
	22	14.7	3.11	.340	.345	0.89	1.07
	23	16.0	-3.46	.258	.359	0.77	1.36
	31	25.1	-0.24	.170	.284	0.88	1.30
	41	16.7	-2.21	.616	.229	0.66	0.44
	42	18.5	1.64	.729	.069	0.76	0.80
	44	7.9	-1.11	.583	.869	0.46	-0.94
	51	17.8	-5.34	.976	.854	0.29	0.19
	52	17.6	5.95	.010	.054	1.23	-1.88
	53	19.5	3.85	.014	.036	1.42	-1.28
	61	22.8	-2.37	.128	.223	1.06	1.40
	64	17.7	3.38	.930	.442	0.28	0.38

Table 12: Test for isotropy of the orientations of galaxy plane. The distribution of the angle δ of galaxies, NSP galaxies, inclination was obtained according to HHV and FP corrections.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
δ	11	27.2	8.78	.006	.025	1.04	-3.07
	12	21.0	6.47	.091	.035	0.92	-2.18
	13	11.2	0.03	.947	.420	0.51	0.32
	14	14.4	7.68	.613	.115	0.55	-0.61
	15	11.9	0.74	.808	.777	0.48	-0.03
	17	6.7	1.16	.900	.815	0.39	-0.01
	21	12.3	-0.57	.802	.947	0.50	-0.13
	22	21.0	-1.43	.900	.965	0.52	-0.30
	23	15.7	3.03	.698	.662	0.44	0.85
	31	16.4	-3.81	.428	.522	0.71	0.23
	41	17.7	-0.62	.327	.653	0.90	1.18
	42	10.2	2.47	.384	.745	0.58	1.07
	44	10.2	1.38	.098	.319	1.05	-0.49
	51	11.0	3.12	.271	.511	0.84	0.96
	52	9.9	2.15	.435	.727	0.78	0.23
	53	26.5	9.98	.005	.008	1.56	0.67
	61	17.4	1.63	.647	.313	0.62	-0.93
	64	19.7	-1.93	.226	.443	0.76	0.29

Table 13: Test for isotropy of the orientations of galaxy plane. The distribution of the angle η of galaxies, inclination was obtained according to HHV and FP corrections.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
η	11	44.1	13.00	.000	.000	1.37	3.77
	12	21.3	3.87	.075	.126	1.65	-0.90
	13	18.3	5.17	.272	.090	0.67	1.53
	14	8.5	0.34	.418	.638	0.45	0.55
	15	22.0	-11.48	.651	.777	0.57	0.72
	17	8.2	-3.05	.603	.852	0.40	-0.65
	21	15.8	-6.45	.718	.912	0.75	0.17
	22	14.6	1.00	.767	.964	0.53	0.73
	23	7.3	-1.18	.809	.956	0.40	0.06
	31	20.2	0.17	.047	.103	0.81	2.31
	41	38.3	20.16	.007	.000	1.61	0.97
	42	20.6	4.94	.729	.023	0.59	0.80
	44	19.5	-3.95	.763	.441	0.55	-0.08
	51	20.8	2.61	.736	.137	0.66	0.71
	52	17.6	-0.37	.085	.276	0.99	0.93
	53	19.3	-3.50	.888	.361	0.51	-0.06
	61	23.7	2.09	.045	.043	1.22	1.39
	64	23.3	-5.65	.289	.291	0.76	1.46

Table 14: Test for isotropy of the orientations of galaxy plane. The distribution of the angle η of galaxies, SP galaxies, inclination was obtained according to HHV and FP corrections.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
η	11	25.3	6.11	.222	.010	0.77	1.68
	12	19.6	3.51	.673	.264	0.77	-0.12
	13	23.5	0.03	.647	.069	1.05	0.91
	14	16.9	0.28	.289	.348	0.78	-1.49
	15	22.0	3.85	.331	.097	1.08	0.27
	17	11.1	-1.39	.659	.906	0.67	0.37
	21	14.0	-5.30	.801	.953	0.45	0.29
	22	21.7	-5.08	.914	.230	0.43	0.33
	23	12.1	-1.76	.895	.977	0.32	-0.47
	31	24.1	0.81	.121	.038	1.48	0.89
	41	21.4	-3.86	.149	.156	0.80	1.95
	42	9.0	-3.32	.872	.935	0.45	-0.27
	44	13.1	-1.12	.322	.466	0.62	1.40
	51	25.6	-1.04	.867	.368	0.90	0.41
	52	14.0	1.80	.112	.223	0.95	0.07
	53	14.4	-2.30	.384	.643	0.61	0.11
	61	14.2	5.27	.067	.068	1.28	1.30
	64	15.3	0.27	.300	.465	0.94	1.33

Table 15: Test for isotropy of the orientations of galaxy plane. The distribution of the angle η of galaxies, NSP galaxies, inclination was obtained according to HHV and FP corrections.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
η	11	29.3	14.70	.000	.000	1.27	4.09
	12	10.3	-1.23	.509	.794	0.40	-0.96
	13	14.5	-4.23	.617	.635	0.60	0.80
	14	32.0	10.08	.004	.002	1.40	2.09
	15	16.0	-3.50	.808	.915	0.67	-0.18
	17	17.9	7.82	.091	.123	1.24	-0.64
	21	14.6	-4.47	.808	.632	0.59	-0.53
	22	12.7	-2.57	.986	.988	0.46	-0.15
	23	12.8	-0.38	.301	.630	0.50	-0.89
	31	14.5	2.69	.167	.237	1.20	0.99
	41	21.3	1.91	.052	.124	1.11	1.79
	42	36.5	16.64	.009	.000	1.89	0.26
	44	15.7	4.14	.479	.101	0.82	-1.21
	51	19.9	1.88	.098	.197	1.05	2.06
	52	21.5	6.32	.030	.050	1.42	2.05
	53	12.5	-3.00	.921	.953	0.49	0.03
	61	14.4	-1.80	.139	.412	0.77	0.37
	64	27.0	-6.00	.458	.692	0.67	1.24

Table 16: Test for isotropy of the orientations of galaxy plane. The distribution of the angle P of galaxies. Only galaxies with certain measure P are taken into account.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
P	11	17.7	-9.32	.991	.910	0.40	-0.01
	12	19.5	0.19	.113	.137	0.99	-0.49
	13	16.7	1.40	.805	.245	0.81	-0.63
	14	14.2	2.21	.943	.196	0.44	-0.34
	15	12.0	-0.86	.201	.381	1.03	0.26
	17	10.7	-5.57	.656	.715	0.58	-0.78
	21	11.2	-3.53	.859	.939	0.55	-0.36
	22	15.1	-1.49	.997	.999	0.57	-0.01
	23	12.3	0.27	.230	.453	0.81	-1.37
	31	23.3	4.07	.444	.052	0.83	0.43
	41	21.3	9.17	.481	.011	1.08	-0.58
	42	18.1	2.38	.075	.172	1.04	-1.59
	44	19.3	-2.14	.352	.694	0.84	0.79
	51	21.0	0.00	.759	.069	0.82	-0.60
	52	8.5	-1.63	.788	.878	0.37	0.68
	53	16.3	0.86	.135	.281	1.24	1.32
	61	27.7	1.38	.040	.011	1.47	-0.54
	64	17.5	3.08	.331	.519	1.14	-1.28

Table 17: Test for isotropy of the orientations of galaxy plane. The distribution of the angle P of galaxies, SP galaxies. Only galaxies with certain measure P are taken into account.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
P	11	20.1	-8.40	.570	.772	0.52	-0.58
	12	16.6	-0.92	.166	.345	0.87	-0.54
	13	15.6	4.80	.430	.073	0.79	-1.21
	14	15.6	4.53	.406	.199	0.67	-0.54
	15	14.0	-2.50	.275	.482	1.00	-0.39
	17	11.7	-5.00	.702	.733	0.62	0.00
	21	21.4	-8.66	.657	.662	0.88	-0.82
	22	13.8	-1.09	.847	.987	0.67	-0.36
	23	12.8	1.69	.272	.270	0.78	-0.74
	31	18.2	-1.39	.266	.169	0.74	-0.45
	41	20.0	8.35	.850	.012	0.74	-0.10
	42	14.6	1.34	.149	.236	0.89	-0.91
	44	16.0	-3.00	.371	.700	0.71	0.46
	51	21.0	-1.50	.817	.075	0.82	-0.48
	52	7.6	0.17	.376	.673	0.55	1.32
	53	17.0	-4.94	.511	.719	0.76	0.61
	61	22.4	-2.18	.133	.078	1.11	-0.23
	64	16.0	3.00	.506	.369	1.18	-0.69

Table 18: Test for isotropy of the orientations of galaxy plane. The distribution of the angle P of galaxies, NSP galaxies. Only galaxies with certain measure P are taken into account.

angle	group	χ^2	C	$P(\Delta_1)$	$P(\Delta)$	λ	$\Delta_{11}/\sigma(\Delta_{11})$
P	11	15.3	5.96	.101	.158	0.85	1.32
	12	14.0	1.00	.664	.408	0.47	0.00
	13	11.6	-1.00	.640	.889	0.74	0.83
	14	17.4	-2.17	.350	.369	0.82	0.12
	15	12.0	3.00	.180	.167	0.95	1.64
	17	11.0	-1.86	.374	.665	0.59	-1.35
	21	16.0	-7.00	.759	.734	0.71	0.73
	22	19.4	-1.14	.818	.951	0.59	0.44
	23	26.4	-7.00	.269	.379	0.65	-1.54
	31	30.0	6.00	.171	.045	1.44	1.83
	41	9.0	1.50	.330	.436	0.96	-0.97
	42	16.8	2.09	.178	.331	0.80	-1.85
	44	15.0	3.00	.613	.262	0.96	0.99
	51	9.0	0.00	.916	.924	0.38	-0.40
	52	27.0	-3.00	.097	.155	0.87	-1.22
	53	14.2	1.60	.115	.319	1.17	1.60
	61	18.0	4.50	.180	.167	1.15	-0.83
	64	16.1	-1.86	.422	.648	0.50	-1.31

- [10] Wesson, P. S. 1982, *Vistas Astron.*, 26, 225
- [11] Silk, J., Efstathiou, G. A. 1983, *The Formation of Galaxies, Fundamentals of Cosm. Phys.* 9, 1
- [12] Dekel, A. 1985, *Astron.J.*, 298, 461
- [13] Bower, R. G., Benson, A.J., Malbon, R., Helly, J., Frenk, C. S., Baugh, C. M., Cole, S., Lacey, C. G. 2006, *MNRAS*, 370, 645
- [14] Godłowski, W. 2011, *IJMPD*, 20, 1643
- [15] Godłowski, W., Szydlowski, M., Flin, P. 2005, *Gen. Rel. Grav.* 37, (3) 615
- [16] Aryal, B., Paudel, S., Saurer, W. 2007, *MNRAS*, 379, 1011
- [17] Hwang, H.S., Lee M.G., 2007 *Astroph. J.* 662, 236
- [18] Thompson, L.A., 1976 *Astrophys. J.*, 209, 22
- [19] Adams, M.T., Strom, K.M., Strom, S.E., 1980 *Astrophys. J.*, 238, 445
- [20] Helou, G., Salpeter, E.E., 1982 *Astroph. J.*, 252, 75
- [21] MacGillivray, H.T., Dodd, R.J., 1985a in: *ESO Workshop on the Virgo Cluster*, ESO, ed. B. Binggeli Garching bei Munchen, p.217
- [22] Bukhari, F.A., 1988 *Astrophys. J.*, 333, 564
- [23] Bukhari, F.A., Cram, L.E., 2003 *Astrop. and Space Science*, 283, 169
- [24] Han, C., Gould, A., Sackett, P., 1995 *Astrophys. J.*, 445, 46
- [25] Flin, P., Olowin, R.P., 1991 in: *Physical Cosmology*, eds. A.Blanchard, L. Celniker, M. Lachieze-Rey, Tran Thanh Van, Edition Frontiere, Gif-sur-Yvette, p.512
- [26] Trevese, D., Cirimele, G., Flin, P., 1992 *Astronom. J.*, 104, 935
- [27] Kim, R., 2001 in: *American Astronomical Society, 199 AAS Meeting, Bulletin of the American Astronomical Society* vol 33, p.1521
- [28] Torlina, L., De Propriis, R., West, M.J., 2007 *Astroph. J.* 660, L97
- [29] Gonzalez-Sanchez, A., Teodoro L., 2010 *MNRAS*, 404, L11
- [30] Godłowski, W., Baier, F.W. MacGillivray, H.T., 1998, *A&A*, 339, 709
- [31] Baier, F. W., Godłowski, W., MacGillivray, H. T. 2003, *A&A*, 403,847
- [32] Djorgovski S., 1983 *Astrophys. J.*, 274, L11
- [33] Kitzbichler, M.G., Saurer, W., 2003 *Astroph. J.*, 590, L9
- [34] Wu G.X., Hu F.X., Su H.J., Liu Y.Z., 1998 *Chin. Astron. Astrophys.*, 22, 17

- [35] Tully, R. B. 1988, *Nearby Galaxy Catalog*, Cambridge
- [36] Godłowski, W., Ostrowski, M., 1999, *MNRAS*, 303, 50
- [37] Heidmann, J., Heidmann, N., de Vaucouleurs 1972 *Mem.R.Ast.Soc.* 75, 85
- [38] Fouque, P., Paturel, G., 1985 *A&A*, 150, 192
- [39] Tully, R. B. 1987, *Astrophys. J.*, 321, 280
- [40] Nilson, P. 1973, *Uppsala General Catalogue of Galaxies*, *Astr. Obs. Ann. V.*, Vol.1: Uppsala
- [41] Nilson, P. 1974 *Catalogue of Selected Non-UGC Galaxies*, *Uppsala Astr. Obs. Rep. 5*: Uppsala
- [42] Labuerts, A. 1982, *ESO/Uppsala Survey of the ESO B Atlas*, *ESO: Garching*
- [43] Lauberts, A., Valentijn, E. 1989, *The Surface Photometry Catalogue of the ESO-Uppsala Galaxies*, *ESO:Garching*
- [44] Godłowski, W., Flin, P., 2010, *Astrophys. J.*, 708, 902
- [45] Tully, R. B., Shaya, E. J. 1984, *Astrophys. J.*, 281, 31
- [46] Öpik, E.J. 1970, *Irish AJ*, 9, 211
- [47] Jaaniste, J., Saar, E. 1978, in: *The large scale structures of the Universe.*, eds. M. S. Longair and J. Einasto, D. Reidel, Dordrecht (IAU Symp. 79), p.488
- [48] Flin, P., Godłowski, W. 1986, *MNRAS*, 222, 525
- [49] Flin, P., Godłowski, W., 1989 *Sov. Astron. Lett.* 15, 374 (*Pisma w Astronomiczeskij Zurnal* 15, 867)
- [50] Flin, P., Godłowski, W., 1990 *Sov. Astron. Lett.* 65, 209 (*Pisma w Astronomiczeskij Zurnal* 16, 490)
- [51] Godłowski, W. 1993, *MNRAS*, 265, 874
- [52] Godłowski, W. 1994, *MNRAS*, 271, 19
- [53] Aryal, B., Saurer, W., 2000, *A&A*, 364, L97
- [54] Holmberg, E., 1946 *Medd. Lund. Astron. Obs. Ser. VI*, Nr.117
- [55] Tammann, G. A., Sandage, A. 1976 *Astrophys. J.*, 207, L1
- [56] Aryal, B., Saurer, W. 2004, *A&A*, 425, 871
- [57] Aryal, B., Saurer, W. 2005, *A&A*, 432, 431
- [58] Aryal, B., Saurer, W. 2006, *MNRAS*, 336, 438
- [59] Catelan, P., Theuns, T. 1996 *MNRAS*, 282, 436

- [60] Li, Li-Xin., 1998, *Gen. Rel. Grav.*, 30, 497
- [61] Paz, D.J, Stasyszyn, F., Padilla, N. D. 2008, *MNRAS*, 389, 1127
- [62] Jones, B., van der Weygaert R., Aragon-Calvo M., 2010 *MNRAS*, 408, 897
- [63] Silk, J. 1968, *Astrophys. J.*, 151, 459
- [64] Peebles, P.J.E., Yu, J., T. 1970, *Astrophys. J.*, 162, 815
- [65] Sunyaev, A. R., Zeldovich, Ya. B., 1970, *Astroph. Sp. Sci.*, 7, 3
- [66] Springel, V., et al. 2005, *Nature*, 435, 629
- [67] van de Weygaert, R., Bond, J. R. 2008, *A Pan-Chromatic View of Clusters of Galaxies and the Large - Scale Structures*, Plionis, M., Lopez-Cruz, O., Hughes D. Springer: Dordrecht, 335
- [68] van de Weygaert, R., Bond, J. R. 2008, *A Pan-Chromatic View of Clusters of Galaxies and the Large - Scale Structures*, Plionis, M., Lopez-Cruz, O., Hughes D. Springer: Dordrecht, 409
- [69] Codis, S., Pichon, C., Devriendt, J., Slyz, A., Pogosyan, D., Dubois, Y., Sousbie, T., 2012, *MNRAS*, 427, 3320
- [70] Wesson, P. S. 1979, *A&A*, 80, 269
- [71] Wesson, P. S. 1983, *A&A*, 119, 313
- [72] Carrasco, L., Roth, M., Serrano, A. 1982, *A&A*, 106, 89
- [73] Brosche, P. 1986, *Comm. Astroph.*, 11, 213
- [74] Romanowsky, A. J., Fall, S. M., 2012, *arXiv* 1207.4189
- [75] Schfer, B. M. 2009, *IJMPD*, 18, 173
- [76] Heavens, A., Peacock, J. 1988, *MNRAS*, 232, 339
- [77] Noh, Y., Lee, J. 2006, *astro-ph/0602575*
- [78] Noh, Y., Lee, J. 2006, *Astrophys. J.*, 652, L71

Table 19: The results of numerical simulations for positions angles P

Sample	Test	\bar{x}	$\sigma(x)$	$\sigma(\bar{x})$	$\sigma(\sigma(x))$
All	χ^2	16.9524	1.4592	0.0461	0.0326
	$\Delta_1/\sigma(\Delta_1)$	1.2513	0.1543	0.0048	0.0034
	$\Delta/\sigma(\Delta)$	1.8772	0.1581	0.0050	0.0035
SP	χ^2	17.0283	1.3628	0.0431	0.0305
	$\Delta_1/\sigma(\Delta_1)$	1.2552	0.1544	0.0049	0.0035
	$\Delta/\sigma(\Delta)$	1.8827	0.1543	0.0049	0.0035
NSP	χ^2	17.1042	1.3485	0.0426	0.0302
	$\Delta_1/\sigma(\Delta_1)$	1.2607	0.1541	0.0049	0.0034
	$\Delta/\sigma(\Delta)$	1.8900	0.1595	0.0050	0.0036

Table 20: The statistics of the observed distributions for real clusters

Sample	Test	P		δ_D		η	
		\bar{x}	$\sigma(x)$	\bar{x}	$\sigma(x)$	\bar{x}	$\sigma(x)$
A_{all}	χ^2	17.34	1.06	23.79	2.85	26.58	2.95
	$\Delta_1/\sigma(\Delta_1)$	1.28	0.18	1.85	0.26	2.44	0.29
	$\Delta/\sigma(\Delta)$	2.11	0.21	2.33	0.26	2.91	0.27
A_{sp}	χ^2	16.61	0.91	18.93	1.18	19.95	1.65
	$\Delta_1/\sigma(\Delta_1)$	1.26	0.12	1.31	0.16	1.53	0.16
	$\Delta/\sigma(\Delta)$	2.13	0.18	1.98	0.14	2.18	0.17
A_{nsp}	χ^2	19.10	1.16	27.79	4.16	27.03	3.61
	$\Delta_1/\sigma(\Delta_1)$	1.45	0.15	2.45	0.27	2.78	0.33
	$\Delta/\sigma(\Delta)$	1.97	0.17	2.87	0.28	3.27	0.33
B_{all}	χ^2	16.80	1.15	18.70	1.33	20.19	2.17
	$\Delta_1/\sigma(\Delta_1)$	1.22	0.18	1.42	0.17	1.55	0.23
	$\Delta/\sigma(\Delta)$	2.08	0.22	2.08	0.17	2.39	0.30
B_{sp}	χ^2	16.36	0.89	18.24	1.13	17.68	1.25
	$\Delta_1/\sigma(\Delta_1)$	1.28	0.11	1.26	0.21	1.28	0.15
	$\Delta/\sigma(\Delta)$	2.07	0.18	2.15	0.16	2.12	0.20
B_{nsp}	χ^2	16.56	1.41	15.57	1.37	19.07	1.77
	$\Delta_1/\sigma(\Delta_1)$	1.43	0.12	1.38	0.20	1.78	0.26
	$\Delta/\sigma(\Delta)$	1.97	0.15	1.94	0.20	2.19	0.28